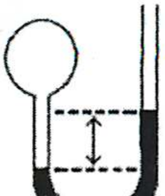
Gas Law Problems

1. A gas vessel is attached to an open-end manometer filled with a nonvolatile liquid of density 0.993 g/mL as shown below.



The difference in heights of the liquid in the two sides of the manometer is 32.3 mm when the atmospheric pressure is 765 mmHg. Given that the density of mercury is 13.6 g/mL, the pressure of the enclosed gas is __________ atm. What is this pressure in kPa?

$P_{gas} = (765\,mmHg + 32.3\,mm\,Hg) \times \frac{1\,atm}{760\,mmHg} = \boxed{1.04\,atm} \times \frac{101.3\,kPa}{1\,atm} = \boxed{105\,kPa}$

2. A sample of gas (24.2 g) initially at 4.31 atm was compressed from 8.00 L to 2.00 L at constant temperature. What is the new pressure, after the compression?

$P_2 = \frac{V_1 P_1}{V_2} = \frac{(8.00L)(4.31atm)}{(2.00L)} = \boxed{17.2\,atm}$

3. A balloon originally had a volume of 4.39 L at 44.0 °C and a pressure of 729 torr. The balloon must be cooled to what temperature to reduce its volume to 3.78 L (at constant pressure).

$T_2 = \frac{V_2 T_1}{V_1} = \frac{(3.78L)(44°C+273)}{4.39L} = 273K - 273 = \boxed{0\,°C}$

4. A sample of He gas (2.35 mol) occupies 57.9 L at 25.0 K and 1.00 atm. The volume of this sample is __________ L at 423 K and 1.34 atm.

$V_2 = \frac{V_1 P_1 T_2}{P_2 T_1} = \frac{(57.9L)(1.00atm)(423K)}{(1.34atm)(25°C+273K)} = \boxed{61.3\,L}$

5. If 3.21 mol of a gas occupies 56.2 L at 34.0 °C and 793 torr, what volume will 5.29 mol of this gas occupy under these conditions.

$V = \frac{nRT}{P} = \frac{(5.29mol)(0.08206\frac{L\,atm}{mol\,K})(34.0°C+273)}{\left(\frac{793\,torr}{760\,torr/atm}\right)} = \boxed{130.\,L}$

6. A sample of gas (1.9 mol) is in a flask at 21 °C and 697 mmHg. The flask is opened and more gas is added to the flask. The new pressure is 795 mmHg and the temperature is now 26 °C. How many moles of gas are in the flask?

$V = \frac{nRT}{P} = \frac{(1.9mol)(0.08206\frac{L\,atm}{mol\,K})(21°C+273)}{\frac{697\,torr}{760\,torr/atm}} = 50\,L$ flask

$n = \frac{PV}{RT} = \frac{\left(\frac{795\,mmHg}{760\,mm/atm}\right)(50L)}{(0.08206\frac{L\,atm}{mol\,K})(26°C+273)} = \boxed{2.1\,mol\ of\ gas}$

7. What is the density of ammonia gas (g/L) in a 4.32 L container at 837 torr and 45.0 °C?

$D = \frac{MP}{RT} = \frac{(17.0\frac{g}{mol})\left(\frac{837\,torr}{760\,torr/atm}\right)}{(0.08206\frac{L\,atm}{mol\,K})(45°C+273)} = 1.04\,\frac{g}{L}$

8. A sample of a volatile alkane liquid was injected into a flask (m_{flask} = 27.0928 g, V_{flask} = 0.1040 L) and heated until no visible traces of the liquid could be found. The flask and its contents were then rapidly cooled and reweighed ($m_{flask + vapor}$ = 27.4593 g) The atmospheric pressure and temperature during the experiment were 0.976 atm and 18.0 °C, respectively. Which alkane was used in this experiment?

$m_{vapor} = 27.4593g - 27.0928g = 0.3665g$

$n_{gas} = \frac{PV}{RT} = \frac{(0.976atm)(0.1040L)}{(0.08206\frac{L\,atm}{mol\,K})(18°C+273)} = 0.00425mol$

$\frac{0.3665\,g}{0.00425\,mol} = 86.2\,g/mol$

for alkane C_nH_{2n+2}

$(12\frac{g}{mol})x + 1\frac{g}{mol}(2x+2) = 86.2\frac{g}{mol}$ $\boxed{hexane}$

$14x + 2 = 86$ $x = 6$

Multiple Choice (NO CALCULATOR)

1. Of the following, __________ is a greenhouse gas.

A) O_2 D) C_2H_4
B) CH_4 E) Xe
C) Cl_2

2. Which of the following statements about gases is false?

A) Gases are highly compressible.
B) Distances between molecules of gas are very large compared to bond distances within molecules.
C) Non-reacting gas mixtures are homogeneous.
D) Gases expand spontaneously to fill the container they are placed in.
E) All gases are colorless and odorless at room temperature.

3. Of the following, __________ has a slight odor of bitter almonds and is toxic.

A) NH_3 D) CH_4
B) N_2O E) HCN
C) CO

4. Of the following, __________ has the odor of rotting eggs.

A) NH_3 D) NO_2
B) H_2S E) HCN
C) CO

5. One significant difference between gases and liquids is that __________.

A) a gas is made up of molecules
B) a gas assumes the volume of its container
C) a gas may consist of both elements and compounds
D) gases are always mixtures
E) All of the above answers are correct.

6. Molecular compounds of low molecular weight tend to be gases at room temperature. Which of the following is most likely not a gas at room temperature?

A) Cl_2 D) H_2
B) HCl E) CH_4
C) LiCl

7. Gaseous mixtures __________.

A) can only contain molecules
B) are all heterogeneous
C) can only contain isolated atoms
D) are all homogeneous
E) must contain both isolated atoms and molecules

8. Of the following, __________ *is a valid statement* of Charles' law.

A) $\frac{P}{T}$ = constant
B) $\frac{V}{T}$ = constant
C) PV = constant
D) V = constant × n
E) V = constant × P

9. The volume of an ideal gas is zero at __________.

A) 0 °C D) -363 K
B) -45 °F E) -273 °C
C) -273 K

10. The density of __________ is 0.900 g/L at STP.

A) CH_4 D) N_2
B) Ne E) NO
C) CO

11. The kinetic-molecular theory predicts that pressure rises as the temperature of a gas increases because __________.

A) the average kinetic energy of the gas molecules decreases
B) the gas molecules collide more frequently with the wall
C) the gas molecules collide less frequently with the wall
D) the gas molecules collide more energetically with the wall
E) both the gas molecules collide more frequently with the wall and the gas molecules collide more energetically with the wall

12. Equal masses of three different ideal gases, X, Y, and Z, are mixed in a sealed rigid container. If the temperature of the system remains constant, which of the following statements about the partial pressure of gas X is correct?

(A) It is equal to 1/3 the total pressure
(B) It depends on the intermolecular forces of attraction between molecules of X, Y, and Z.
(C) It depends on the relative molecular masses of X, Y, and Z.
(D) It depends on the average distance traveled between molecular collisions.
(E) It can be calculated with knowledge only of the volume of the container.

Gas Stoichiometry Problems (Reaction Review Too)

1. What volume (mL) of gas can be produced by the complete reaction of 3.82 g of calcium sulfite with excess HCl (aq), when the final pressure in the reaction vessel is 827 torr at 44.0 °C?

$CaSO_3 + 2HCl \rightarrow CaCl_2 + H_2O + SO_2$

$3.82g\ CaSO_3 \times \frac{1mol\ CaSO_3}{90g\ CaSO_3} \times \frac{1mol\ SO_2}{1mol\ CaSO_3} = 0.0424mol\ SO_2$

$V = \frac{(0.0424)(R)(317K)}{0.998atm} = 1.11L \times \frac{1000mL}{1L}$ = **1110 mL**

$P = 827torr - 68.8torr = 758torr \times \frac{1atm}{760} = 0.998atm$

$\ln\frac{23.8}{P_2} = \frac{43910(1000)}{8.3145}\left(\frac{1}{317K} - \frac{1}{298}\right) \rightarrow \ln\frac{23.8}{P_1} = -1.06\quad P_{44} = 68.8$

$44.0°C + 273 = 317K$

(CC Eqn)

2. Automobile air bags use the decomposition of sodium azide (NaN_3) as their source of gas for rapid inflation. What mass (g) of NaN_3 is required to provide 40.0 L of gas at 25.0 °C and 763 torr?

$2NaN_3 \rightarrow 2Na + 3N_2$

$P = 763torr \times \frac{1atm}{760torr} = 0.996atm$

$n = \frac{(40.0L)(0.996atm)}{R\ 298K} = 1.63mol\ N_2 \times \frac{2mol\ NaN_3}{3mol\ N_2} \times \frac{65g\ NaN_3}{1mol\ NaN_3}$ = **70.6 g NaN_3**

$T = 25°C + 273 = 298K$

$V = 40.0L$

3. What volume (L) of gas at STP is produced by the complete reaction of 7.5 g of water and 12.5 g of magnesium nitride? What is the pH of the resulting solution?

$Mg_3N_2 + 6H_2O \rightarrow 3Mg(OH)_2 + 2NH_3$

$7.5g\ H_2O \times \frac{1mol\ H_2O}{18g\ H_2O} \times \frac{1mol\ Mg_3N_2}{6mol\ H_2O} = 0.069mol\ Mg_3N_2$ Need (0.416mol H_2O have LR)

$12.5g\ Mg_3N_2 \times \frac{1mol\ Mg_3N_2}{100g\ Mg_3N_2} = 0.125mol\ Mg_3N_2$ have

$0.416mol\ H_2O \times \frac{2mol\ NH_3}{6mol\ H_2O} \times \frac{22.4L\ NH_3}{1mol\ NH_3}$ = **3.11 L NH_3**

No soln b/c all H_2O is used ↑. So solid $Mg(OH)_2$ produced. (Trick Q)

4. If 2.00 g of copper metal is exposed to 25.0 mL of 0.500 *M* nitric acid, what volume of gas is produced at 20.0°C and 1.31 atm? What is the color of the gas produced? Brown

$Cu \rightarrow Cu^{2+} + 2e^-$

$2H^+ + NO_3^- + e^- \rightarrow NO_2 + H_2O$

$Cu + 4H^+ + 2NO_3^- \rightarrow Cu^{2+} + 2NO_2 + H_2O$

$2.00g\ Cu \times \frac{1mol\ Cu}{63.5g\ Cu} = 0.0315mol\ Cu \times \frac{4mol\ H^+}{1mol\ Cu} = 0.126mol\ H^+$

$25.0mL \times \frac{1L}{1000mL} \times 0.500M\ HNO_3 \times \frac{1mol\ H^+}{1mol\ HNO_3} = 0.0125mol\ H^+ \times \frac{2mol\ NO_2}{4mol\ H^+} = 0.00625mol\ NO_2$ LR

$1.31atm \times \frac{760torr}{1atm} = 995.6 - 17.5torr = 978.1torr \times \frac{1atm}{760torr} = 1.29atm$

$V = \frac{(0.00625mol)R(293K)}{1.29atm}$ = **0.117 L**

5. What is the total pressure in a 1.500 L flask after 10.0g solid ammonium nitrate is heated to 400.0C? Assume the compound was initially in a vacuum, and that temperature does not change throughout the procedure.

$2NH_4NO_3 \rightarrow 2N_2 + 4H_2O + O_2$

$10.0g\ NH_4NO_3 \times \frac{1mol\ NH_4NO_3}{80g\ NH_4NO_3} \times \frac{2mol\ N_2}{2mol\ NH_4NO_3} = 0.125mol\ N_2$

$\times \frac{4mol\ H_2O}{2mol\ NH_4NO_3} = 0.250mol\ H_2O$

$\times \frac{1mol\ O_2}{2mol\ NH_4NO_3} = 0.0625mol\ O_2$

0.4375 mol total

$P = \frac{(0.4375mol)(R)(673K)}{1.500L}$ = **16.11 atm**

Graham's Law Questions

1. Compare the diffusion rate of ammonia to sulfur dioxide.

$$\frac{Rate_{NH_3}}{Rate_{SO_2}} = \sqrt{\frac{M_{SO_2}}{M_{NH_3}}} = \sqrt{\frac{64\,g/mol}{17\,g/mol}} = 1.94x \leftarrow NH_3\ 1.94x\ faster$$

2. An unknown gas composed of homonuclear diatomic molecules effuses at a rate only 0.355 times that of oxygen gas at the same temperature. What is the identity of the unknown gas?

$$\sqrt{\frac{M_{O_2}}{M_x}} = 0.355 \quad \text{or} \quad \sqrt{\frac{32.0\,g/mol}{M_x}} = 0.355$$

$M_x = 254\ g/mol \Rightarrow I_2$

3. Hydrogen has two naturally occurring isotopes, ^1H and ^2H. Chlorine also has two naturally occurring isotopes, ^{35}Cl and ^{37}Cl. Thus, hydrogen chloride gas consists of four distinct types of molecules: $^1H^{35}Cl$, $^1H^{37}Cl$, $^2H^{35}Cl$, and $^2H^{37}Cl$. Place these four molecules in order of increasing rate of effusion.

$^2H^{37}Cl < {}^1H^{37}Cl < {}^2H^{35}Cl < {}^1H^{35}Cl$

4. Arsenic(III) sulfide sublimes readily, even below its melting point of 320°C. The molecules of the vapor are found to effuse through a tiny hole at 0.28 times the rate of effusion of Ar atoms under the same temperature and pressure conditions. What is the molecular formula of arsenic(III) sulfide in the gas phase?

$$\sqrt{\frac{M_{Ar}}{M_x}} = 0.28 \qquad \sqrt{\frac{40.00}{M_x}} = 0.28 \qquad M_x = 510\ g/mol$$

$As_2S_3 = 246\ g/mol$

$\frac{510\,g}{246} = 2.07 \rightarrow As_4S_6$

Non-Ideal Gas Behavior Questions

5. Calculate the pressure that Cl_2 will exert at 40.0°C if 1.00 mol occupies 28.0 L, assuming that **(a)** Cl_2 obeys the ideal gas law; **(b)** Cl_2 obeys the van der Waals equation. (Values for the van der Waals constants are on page 210 in Zumdahl.)

a $P = \frac{(1.00\,mol)(0.08206)(40°C+273)}{28.0\,L} = 0.917\ atm$

b $\left(P_{obs} + a\left(\frac{n}{V}\right)^2\right) \times (V - nb) = nRT$

$\left(P_{obs} + (6.49)\left(\frac{1.00\,mol}{28.0\,L}\right)^2\right)(28.0\,L - (1.00\,mol)(0.0562)) = 1.00(R)(313\,K)$

$P_{obs} = 0.911\ atm$

6. Large amounts of nitrogen gas are used in the manufacture of ammonia, principally used in fertilizers. Suppose 80.00 kg of $N_2(g)$ is stored in a 1000.0 L metal cylinder at 300.0°C. **(a)** Calculate the pressure of the gas assuming ideal-gas behavior. **(b)** Calculate the pressure assuming real gas behavior. **(c)** Under the conditions of this problem, which correction dominates, the one for finite volume of gas molecules or the one for attractive interactions?

$80.00\,kg \times \frac{1000\,g}{1\,kg} \times \frac{1\,mol}{28\,g} = 2857\ mol$

$P = \frac{(2857\,mol)(R)(300\,K+273)}{1000\,L} = 134\ atm$

b $\left[P_{obs} + (1.39)\left(\frac{2857}{1000}\right)^2\right](1000 - (2857)(0.0391)) = (1000)(R)(573\,K)$

$P_{obs} = 187\ atm$

c B/c the # of moles are so high the b const matters more